Genetically Improved Eucalypts for Novel Applications and Sites in Florida

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Abstract: Genetic, silvicultural, and propagation improvements collectively can increase the productivity of *Eucalyptus grandis* (*EG)* and *E. amplifolia (EA)* grown for mulchwood, energywood, flooring, and other products on agricultural, forest, and non-traditional sites such as reclaimed mined and contaminated lands in Florida and similar areas. *EG* has been grown commercially in southern Florida since the 1960s, initially for pulpwood and now for mulchwood from some 6,000 ha of plantations on flatwoods in the LaBelle-Palmdale area. *EG*'s commercialization was and is facilitated by multi-agency research resulting in some 3,200 *EG* accessions, over 300 maintained clones, 4th-generation clonal and seedling seed orchards, a 5th-generation seedling seed orchard, and a genetic test base exceeding 50 studies involving over 1,000 o-p progenies, 40 control-pollinated progenies, 300 clones, and 30 hybrids. Development of *EA*, suitable for more temperate climates with more frequent and severe freezes, has been less intensive but has followed a similar genetic improvement strategy, with genetic tests in FL, GA, and LA now numbering 20 and including more than 300 accessions, 25 seed orchard o-p progenies, and 50 clones.

Genetic improvement of *EG* and *EA* can increase the commercial feasibility of short rotation woody crops (SRWC) for energywood and phytoremediation. *EG* and *EA* SRWC cost competitiveness will depend on establishment success, yield improvements, harvesting costs, and identifying/using incentives. While SRWC plantations are intended primarily for energy utilization, coproducts and alternative higher-value uses would improve their economic viability and provide an incentive for development. Development of more freeze-tolerance is still of utmost importance for *EG* and *EA*. In addition to significant improvement of freeze-tolerance, increases in productivity, adaptability to various sites, evaluation of wood properties, and determination of propagation options must be addressed. *EG* seed quantity and quality are currently affected by a high level of variability in flowering time and hurricane blowdown in the clonal seed orchard, but genetic gain potential for growth and freeze-resilience may be realized from the 5th-generation orchard. Larger gains are expected from clonal selection and testing. Strong collaboration among public and private partners is necessary.

Keywords: *Eucalyptus amplifolia*, *E. grandis*, seed orchards, clones, wood properties, windfirmness, short rotation woody crops, phytoremediation.

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INTRODUCTION

EG is grown commercially for mulchwood on ~6,000 ha near Palmdale. This commercialization was made possible by research conducted until 1984 by the US Forest Service in association with several companies (Geary et al. 1983, Meskimen 1983). Since the late 1970s, this research base has been further developed by the University of Florida in collaboration with Lykes Bros. and with support from various agencies to also assess *EG* as a short rotation woody crop (SRWC) for energywood and phytoremediation in southern and recently central Florida (Meskimen et al. 1987, Rockwood et al. 1989, Rockwood and DeValerio 1986, Rockwood and Geary 1988, Rockwood and Meskimen 1991, Warrag et al. 1990). *EG* is best suited to southern Florida's subtropical and tropical flatwoods and muck soils but can also be grown successfully in central Florida (Rockwood 1997). Most available *EG* seedlots are from GO77, a 4th-generation seedling seed orchard established in 1977 and developed through combined tree selection, progeny testing, and provenance testing. A 5th-generation seedling seed orchard offers genetic gain potential (Rockwood et al. 1989), but larger gains are expected from over 250 clones evaluated for tree size, freeze-resilience, survival, and stem form; some 10 clones were comparable to superior clones previously selected (Meskimen et al. 1987). *EG* and *EA* have demonstrated high energywood productivity on reclaimed phosphate mined lands (Segrest et al. 2004).

EA, which coppices prolifically, is an appropriate SRWC for more temperate climates with more frequent and severe freezes and may be grown from central Florida northward to perhaps 50 miles from the Gulf Coast. Development of *EA* has been less intensive but has followed a genetic improvement strategy similar to *EG* (Rockwood et al. 1987, Rockwood et al. 1991, Rockwood et al. 1993).

While SRWCs are intended primarily for energy utilization, coproducts and alternative higher-value uses would improve their economic viability and provide an incentive for development. Cofiring up to 5% SRWCs is the most cost effective means of creating renewable energy (Segrest et al. 2004). A ready commercial alternative for *EG* and *EA* is mulchwood. *EG* has been used for pallet manufacturing. *EG* and *EA* are also very suitable for pulp and paper production, flooring, and very likely reconstituted wood panel products. *EA* and *EG* have phytoremediation potential (Pisano and Rockwood 1997, Rockwood et al. 2004).

Genetic, silvicultural, and propagation improvements collectively can increase the productivity of *EG* and *EA* for SRWC applications on agricultural, forest, and non-traditional sites such as reclaimed mined and contaminated lands. We report recent results on genetic variability in *EG* and *EA* that influence opportunities for these SRWCs in central and southern Florida.

MATERIALS AND METHODS

EG and *EA* studies established at a Lakeland, Florida, clay settling area (CSA) include a demonstration planting, commercial plantings, and a clone-configuration-fertilizer study (SRWC-90). The demonstration area planted in April 2001 had single and double (0.8m apart) row configurations at 0.9m spacing on top of beds spaced 3.4m apart. After periodic size and survival measurements, approximately half of each block was felled in February 2002. Commercial scale plantings of approximately 8 ha in June 2001, June 2002, and/or October 2002 similarly involved single and double rows on beds, as well as quadruple rows of trees planted 0.8m apart on a macrobed or mound. SRWC-90 involves *EG* and *EA* represented by up to six genotypes, two planting configurations (single or double rows per bed), and two fertilizer levels (0 or 100 pounds/acre of ammonium nitrate) in a split-plot design with configuration main plots, species subplots, and genotypes in 6-tree row subsubplots. The initial planting was done in March 2001, and fertilizer treatments were implemented in June 2002. An economic analysis similar to Langholtz et al. (2004) that examined the importance of input costs, harvest prices, progeny, rotation, coppicing, and incorporation of CO_2 mitigation incentives for SRWCs on CSAs in terms of land expectation value (LEV) and annual equivalent (EAE) assumed: a base scenario of 4% interest rate, \$1,800 ha^{-1} site preparation cost, \$1,200 ha^{-1} planting cost, and a carbon price of \$5 Mg^{-1} C.

To assess the significance of clonal variation on wood properties contributing to the use of *EG* for solid wood products, 53 trees (40 identified, 13 unidentified) in GO77 were felled in March 2004 at 26.6 years of age. Stem disks were taken at 1.3m from 40 identified trees, and boards were cut from the basal logs of 22 unidentified trees. After drying, radial strips were cut from the disks and from eight boards, glued to core holders and sawn to ~1.6 mm thick cross sectional strips. The specific gravity for each radial strip was measured by x-ray densitometry at 0.5 mm intervals with a resolution of 2.5 uM (Clark et al., 2004). In addition, the specific gravities of comparative samples from Lyptus® and baldcypress (*Taxodium distichum*) were also measured. As there were no clear earlywood and latewood boundaries, the mean specific gravity was determined by simple averaging.

From 1996-2002, GO96, a clonal seed orchard near Palmdale, assembled 49 fast-growing, freeze-resilient clones from several studies. To assess the influence of flowering time variability on seed production in GO96, onset (Early – Days 218-239, Intermediate – Days 240-258, and Late – Days 259-278) and duration (Short - <25 days, Average – 25-50 days, Long - >50 days) of flowering of 29 clones were observed weekly from August through October 2002. Windfirmness of 45 clones in response to three hurricanes in August-September 2004 was assessed in May 2005 by evaluating 1-18 ramets/clone for lean, broken stem, cut stem, blowdown, or mortality (hurricane damage index (HDI) of 1, 2, 3, 4, and 5, respectively), as influenced by DBH and age.

Progeny test SRWC-100 was established on muck soil at Southwest Ranches in July-August 2002 at 2.4 (within paired rows) or 3.7m (between pairs) x 0.9m spacing with 68 open-pollinated (o-p) progenies in 6 reps of 4-tree row plots according to a randomized complete block design (RCBD). Based on 1.3-year-old height, DBH, survival, and tree quality (0=excellent, …, 4=poor stem straightness/crown form/vigor), SRWC-100 was rogued in March 2004 to create 5th-generation seedling seed orchard GO02. Calculations of basal area/ha (BAH) at 1.3 years (.00007854xDBH^2 for a live tree, 0 for a dead or missing tree) assumed 3,586 trees/ha. Select trees were subsequently reassessed for height, DBH, and tree quality.

In June 2004, 12.6 ha of operational and research plantings of *EG* and *EA* were established in study SRWC-107 near Clewiston, FL, to evaluate cultural and genetic factors important to SRWC energywood production on sandy/muck soil. In the operational single and double (0.8m between paired rows) row plantings (rows or row pairs on 3.1m centers with 0.9m between trees in rows), equivalent to 1,379, 2,760, or 5,520 trees/ha, 26 *EG* and two *EA* progenies were planted in continuous rows of ~306 or 417 trees. Within the operational plantings, cultural and genetic studies were established. The cultural study evaluated three cultures (control, fertilized with 560 kg/ha of 12-10-24 ammonium nitrate, or mulched with 58.3 tons/ha of sugarcane filtercake) in blocks with three replications of two planting configurations (single or double rows) and two *EG* progenies in 13-tree row plots. The genetic study consisted of 29 *EG* and six *EA* progenies planted in June and 37 *EG* progenies (including three planted in June) planted in July in a RCBD with six replications of 6-tree row plots in a double row configuration. In December 2004, height, tree quality, and survival were assessed in the genetic and cultural trials and in three 10m long plots installed at 75m intervals from north to south in each configuration/progeny combination in the operational planting. In May 2005, the northernmost of the 10m long plots and two rows of the June genetics study were remeasured for height and quality.

RESULTS AND DISCUSSION

EA and *EG* comparisons before coppicing were similar in the demonstration area and SRWC-90 at Lakeland. In general, 35-month-old *EA* coppice growth initiated by a Spring 2002 felling of part of the demonstration area was comparable to first rotation growth, but *EG* coppice growth was much less (Table 1). *EA* coppice, thus, appears more reliable and vigorous than that of *EG*.

Table 1. Performance of *EA* and *EG* in the demonstration area on a CSA at Lakeland, Florida.

Configuration - Trait	*EA*	*EG*
Single row 44-mo height (m)	13.1	16.7
Double row 44-mo height (m)	11.9	20.3
Single row 35-mo coppice ht (m)	6.7	7.7
Double row 35-mo coppice ht (m)	9.1	7.3

Average *EG* yields in the commercial plantings at Lakeland are low, as the trees/ha for the single, double, and quadruple configurations are much less than the planted densities (Table 2). The hurricanes of August-September 2004 demonstrated that *EG* SRWCs on CSAs are at risk of blowdown three to four years after planting or coppicing, as ~85% of harvestable trees were severely damaged; younger *EG* and *EA* SRWCs appear much less susceptible to wind damage.

Table 2. Species, culture, establishment date, number (n) of 15m row plots, average tree height (m), DBH(cm), and density (trees/ha) in October 2004 in commercial plantings.

Species	Culture	Est. date	n	Ht	DBH	Density
EG	Single	June 2001	15	9.1	5.8	1823
	Double	July 2000	5	12.2	9.0	1583
	Quadruple	June 2002	8	11.3	3.2	2455
EA	Single	Oct 2001	1	10.1	6.9	3527

In SRWC-90, drought after planting impacted survival. *EG* was first planted in May 2001. Due to high initial mortality, planting was suspended until planting conditions improved with rainfall in July 2001, when *EG* mortality was replaced and *EA* was planted. *EA* and *EG* seedlings typically had survivals exceeding 70%, and *EA* survival usually was over 90%, even at double row configuration of 8,384 trees/ha (Table 3). *EA*, although planted later than and not necessarily as vigorous as *EG*, tended to highest productivity. *EA* and *EG* progenies 5091 and 4200, respectively, were the highest yielding. EG progeny 3242, with the highest initial mortality and follow-up planting, was the lowest yielding progeny.

Table 3. *EA* and *EG* mean, low, and high progeny mean height (m), DBH (cm), and survival (%) at 41 months by unfertilized (U, U1, or U2) and fertilized (F) treatments with single (S) and double (D) row configurations on beds in SRWC-90.

Row Config.	Fert.	Height			DBH			Survival		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
EG										
S	U	8.6	7.5	9.4	6.8	5.3	7.7	85	75	100
	F	8.8	6.9	10.3	6.7	4.5	8.5	82	75	92
D	U1	7.6	6.9	8.6	4.5	3.9	5.5	83	75	88
	U2	9.5	8.2	10.2	6.3	5.0	7.0	71	50	88
	F	11.5	9.1	12.6	8.1	6.0	9.4	59	50	63
EA										
S	U	6.0	4.6	7.8	5.3	3.7	7.3	93	83	100
	F	9.0	7.5	10.0	7.8	6.5	8.7	90	75	96
D	U1	5.3	4.0	5.9	3.6	2.6	4.1	90	75	100
	U2	9.4	7.9	10.6	7.0	5.7	8.1	89	79	100
	F	10.2	8.3	11.2	7.6	6.1	8.8	90	79	100

EA and/or EG SRWC performace on CSAs is improved with herbiciding/disking, bedding, watering/packing seedlings, fertilization with ammonium nitrate, and high planting density. EA can be expected to have high survival on well prepared bedded CSAs, respond favorably to fertilization, tolerate high stand densities, and coppice reliably. EG has the potential to be the most productive species with thorough site preparation and fertilization and properly timed harvesting. EG is best suited for immediate commercialization because of its seed availability, while seed of EA is limited. SRWC rotations can be as short as one year, depending on genotypes, initial planting density, culture intensity, harvesting equipment, and local fiber markets.

For the use of Florida grown *EG* for solid wood products, specific gravity and stiffness are two of the most important traits. Clonal variation in wood specific gravity appears significant for Florida grown *EG* (Table 4). Overall, the GO77 samples were less dense than Lyptus®, a *EG*x*E. urophylla* hybrid that serves as a standard for eucalypt lumber, and more dense than cypress. However, the range in density was great among both sets of *EG* samples, and two known and one unknown *EG* clones were as or more dense than Lyptus®.

Table 4. Mean and range in wood specific gravity (kg/m^3) of *EG* stem disks and boards from GO77, Lyptus®, and cypress.

Sample	Specific Gravity	
	Mean	Range
40 known EG disks	562	429 - 697
8 unknown EG boards	569	477 - 663
Lyptus®	662	650 - 673
cypress	300	293 - 307

Seed quantity and quality in GO96, the only clonal seed orchard of six *EG* seed orchards developed in southern Florida, may be affected by high clonal variability in flowering time (Table 5). The earliest clone started flowering on Day 218, the latest on Day 278. The shortest duration for a clone was 10 days, while the longest duration was 86 days. Collectively, some 28% of the clones observed (two early, one intermediate, four late) did not have overlapping flowering times, very likely contributing to low seed quantities and qualities from GO96.

Table 5. Classification of GO96 clones for onset and duration of flowering in 2002 and wind firmness in 2004.

Category	Clone
Flowering Onset – Duration	
Early – Short; Average; Long	-; 1506, 2805, 3134; 2798,2814,3187,3756,4950,4952,4954,4958,4959,5123,T3
Intermediate – Short; Average; Long	3043; 2422, 3181, 3323; 4960, 4961, 4962, 4964, 4999
Late – Short; Average; Long	2131, 3914, 4986; 2817; -
Windfirmness	
Susceptible (HDI $\geq$3.0)	577, 1506, 1828, 2773, 2798, 3134, 3914, 4950, 4954, 4962, 4986, 5123, T2, T3
Average (1.9< HDI $\leq$3.0)	2519, 2805, 2807, 2814, 3043, 3187, 3756, 4952, 4958, 4963, 4964, 5126, 5139, T9
Resistant (HDI $\leq$1.9)	2131, 2242, 2422, 2817, 3181, 3323, 4959, 4960, 4961, 4999, 5128, 5132, 5137, 5140, 5142, T6

Hurricane damage may reduce GO96 seed production for several years, as 74% of the trees in the orchard sustained some type of damage from the winds that occasionally surpassed 160 km/hour. Tree age and DBH were slightly associated with damage, as only age was correlated with HDI (r=.27), suggesting that the older trees incurred more damage. Some 32% of the clones may be considered susceptible, and 36% appear resistant to damaging winds (Table 5).

The 68 progenies in SRWC-100 varied significantly in DBH, tree quality, and BAH at 1.3 years (Table 6). A wide range in progeny performance evident as early as 4 months, when progeny mean tree heights range from 0.46 to 1.35m, was present a year later as the worst progenies were barely large enough to measure for DBH. After roguing of ~75% of the trees to form GO02, the select trees were more than 2cm larger in average DBH, and the selects from the best progeny were nearly 12m tall. A 5th-generation seedling seed orchard such as GO02 is expected to have good genetic gain potential for growth and freeze-resilience (Rockwood et al. 1989).

Table 6. Summary of *EG* and *EA* progeny means in components of two studies.

Trait	No. of Progenies	Progeny Means		
		Average	Low	High
EG in SRWC-100				
1.3-year DBH (cm)	68	3.74*	0.10	6.50
1.3-year Tree Quality	68	2.5*	0.0	4.0
1.3-year Survival (%)	68	79.5	25.0	100.0
1.3-year BAH (m^2/ha)	68	4.06*	0.68	8.93
EG Selects in SRWC-100				
1.3-year Height (m)	65	7.1	2.6	11.8
1.3-year DBH (cm)	65	6.0	1.9	7.9
1.3-year Tree Quality	65	0.5	0.0	3.0
EG/EA in SRWC-107: Genetics (June and July plantings)				
June: 0.5-year Height (m)	29/6	1.10*/1.17	0.88/1.12	1.27/1.25
June: 0.5-year Survival (%)	29/6	65.3/85.6	38.9/66.7	86.1/94.4
July: 0.4-year Height (m)	37/-	0.79*/-	0.56/-	0.93/-
July: 0.4-year Survival (%)	37/-	88.8/-	61.1/-	100.0/-
EG in SRWC-107: Culture (Control (C), Fertilizer (F), and Mulch (M) amendments)				
C: 0.5-year Height (m)	1	1.12	-	-
C: 0.5-year Survival (%)	1	82.5	-	-
F: 0.5-year Height (m)	1	0.86	-	-
F: 0.5-year Survival (%)	1	61.9	-	-
M: 0.5-year Height (m)	1	1.11	-	-
M: 0.5-year Survival (%)	1	88.1	-	-
EG/EA in SRWC-107: Operational (Single (S) and Double (D) rows)				
S: 0.5-year Height (m)	13/2	1.11*/1.23	0.88/1.23	1.40/1.23
S: 0.5-year Tree Quality	13/2	1.2*/1.7	0.5/1.3	2.7/2.1
S: 0.5-year Survival (%)	13/2	98.9/100.0	80.5/100.0	100.0/100.0
D: 0.5-year Height (m)	14/2	1.17*/1.33	0.97/1.24	1.35/1.53
D: 0.5-year Tree Quality	14/2	1.2*/1.5	0.5/1.4	2.1/1.6
D: 0.5-year Survival (%)	14/2	95.8*/98.6	75.0/95.5	100.0/100.0

*Significant differences among progenies

While GO02 has good genetic gain potential for growth, larger gains may be expected from clonal selection and testing (Meskimen et al. 1987) involving the some 242 accessions retained in GO02 and over 250 clones that have already been evaluated for tree size, freeze-resilience, survival, and stem form. Some 10 of the 250 clones were comparable to superior clones previously selected (Meskimen et al. 1987). Large numbers of rooted cuttings can be produced from these superior clones, and four clones have been micropropagated commercially. While productivity of cuttings and plantlets may greatly exceed that of seedlings, seedling cost favors the commercial use of improved seedlings (Rockwood and Warrag 1994).

The operational, cultural, and genetic plantings established by Florida Crystals (FCC) illustrate the critical factors for SRWC energywood production (Table 6). In comparison to the 1.3-year-old results from SRWC-100 in which superior trees were over 70% larger in DBH and 100%

greater in basal area/ha (BAH) than the average progeny, the heights of the best 0.5-year-old progenies in SRWC-107 were only 15% greater than average. *EA* was surprisingly comparable to *EG* in height and had better survival. The very unusual weather at and following establishment of SRWC-107 also influenced cultural responses, as fertilizer and mulch amendments had unexpectedly similar heights and survivals to the control. Overall, these collective results suggest that FCC, which farms over 70,000 ha in southern Florida and operates the 74 MW Okeelanta Cogeneration Plant by burning bagasse and wood waste, could increase the productivity of operational SRWC plantings of *EG* for energywood on 800 ha of former sugarcane lands by up to 50 % by incorporating appropriate cultural and genetic factors.

Stability of *EA* and *EG* progeny performance across these widely different sites in Florida is difficult to assess due to the limited number of progenies common to Studies SRWC-90, -100, and -107 (Table 7) and because of the young age of SRWC-107, although SRWC-107 trees grew ~2m in height from December 2004 to May 2005. Because the CSAs represented by SRWC-90 and mucks represented by SRWC-100 and -107 are much more fertile than the sandy soils on which GO77 and GO96 are located, some GxE interaction is likely.

Table 7. Mean heights (H in m) or BAH (m^2/ha) at indicated age in months for *EG* progeny common to six studies at three sites.

	SRWC-90	SRWC-100	SRWC-107			
Progeny	H41	BAH16	June H06	July H05	Single H06	Double H06
3242	9.1	4.23				
3469	12.6	5.32		0.70		
3931		3.07	0.88		0.87	1.00
4064	12.6	3.21	1.17			
4200	11.9	3.94				
4223	11.3	3.73	1.20		0.95	1.14
All	11.5	4.06	1.10	0.79	1.11	1.17

The economics for *EG* grown with sewage effluent (Langholtz et al. 2004) exemplify the merit of using improved SRWC genotypes. Average *EG* without coppice produced the least return, and *EG* average with coppice was more profitable. However, faster growing progenies such as *EG* 3309 increased profitability, especially without coppicing, as LEV was $2967/acre and EAE was $118/acre/year. *EG* progeny 3309 had significantly higher yields, was most profitable without coppice, and had a LEV of $7,300 ha^{-1}, EAE of $290 ha^{-1} yr^{-1}, and internal rate of return (IRR) of 29%, with an optimal rotation age of 33 months. Overall returns for the average *EG* progeny were considerably less, but LEVs still exceeded $2,470 ha^{-1} (with coppicing). Whether coppicing is preferable to harvesting\replanting depends on relative seedling and coppice yields, seedling establishment costs, and output prices.

For SRWCs produced on CSAs under various scenarios of operational costs, productivity, stumpage price, and incorporation of CO_2 mitigation incentives, LEVs increased with growth rate and biomass stumpage price. LEVs ranged from $-2,789 to $4,616 ha^{-1} and $-224 to $18,121 ha^{-1} assuming stumpage prices of $10 and $30 Mg^{-1}. Under these assumptions, marginal increases in LEV per dollar increment in stumpage price range from $264-$293 and $588-$629 for low and high growth scenarios, respectively.

While potential products from SRWCs include mulch, energy, timber, pallets, and fiberboard, the most likely are 1) mulchwood and 2) energywood, a prospective market with much potential for expansion. Successful demonstration of SRWC production and cofiring in Florida could lead to SRWC development in the Gulf Coast region and similar environments. *EA* has adaptability for the lower Gulf Coast, and improved *EG* will be suitable for central and southern Florida. SRWCs may also serve as “bridge crops” to restore cogongrass infested CSAs to native forest or productive agricultural lands (Tamang et al. 2004). *EA* and/or *EG*–based phytoremediation systems may have SRWC production potential on a wide range of contaminated sites (Rockwood et al. 2004).

While *EG* and *EA* growth potential is quite high, SRWC cost competitiveness will depend on establishment success, yield improvements, harvesting costs, and identifying/using incentives. Genetic improvement must continue if *EG* and *EA* are to increase in commercial feasibility. Development of more freeze-tolerance is still of utmost importance for *EG* and *EA*. In addition to significant improvement of freeze-tolerance, increases in productivity, adaptability to various sites, evaluation of wood properties, and determination of propagation options must be addressed (Rockwood et al. 1993). The *EG* test base exceeds 50 studies, primarily in southern FL, involving over 1,000 o-p progenies, 40 control-pollinated progenies, 300 clones, and 30 hybrids. *EA* genetic tests in FL, GA, and LA now number 20 and include more than 300 accessions, 25 o-p progenies, and 50 clones. Strong collaboration among public and private partners is essential for commercializing SRWCs.

CONCLUSION

Genetic improvement of *EG* and *EA* can increase the commercial feasibility of SRWCs for mulchwood, energywood, and phytoremediation. *EG* and *EA* SRWC cost competitiveness will depend on establishment success, yield improvements, harvesting costs, and identifying/using incentives. While SRWC plantations are intended primarily for energy utilization, coproducts and alternative higher-value uses would improve their economic viability and provide an incentive for development. Development of more freeze-tolerance is still of utmost importance for *EG* and *EA*. In addition to significant improvement of freeze-tolerance, increases in productivity, adaptability to various sites, evaluation of wood properties, and determination of propagation options must be addressed. *EG* seed quantity and quality are currently affected by a high level of variability in flowering time and hurricane blowdown in the clonal seed orchard, but genetic gain potential for growth and freeze-resilience may be realized from the 5th-generation orchard. Larger gains are expected from clonal selection and testing. Strong research collaboration is necessary.

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